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Military and Potential Homeland Security Applications for Microelectromechanical Systems (MEMS)

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PREFACE

This work was supported by a Central Research Program (CRP) task at the Institute for Defense Analyses (IDA).

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EXECUTIVE SUMMARY

In 1995, the Department of Defense (DoD) identified potential applications of MEMS technology in 12 types of military systems or subsystems. These applications were based on three major areas: Inertial Measurement Systems (IMSs), distributed sensing and control, and information technology (IT) (Ref. 1). The Defense Advanced Research Projects Agency (DARPA) was supporting MEMS technology development in these areas as early as 1992.

MEMS technology is being used in military systems in each of these areas. DARPA and the Armed Services continue to support MEMS technology advancements through several research and development (R&D) programs.

Systems for homeland security will require much of the same functionality as that required for similar military systems. For example, personal protective equipment (PPE) for warfighters may be similar to equipment needed for homeland security first responders (e.g., law enforcement officials and firefighters). This commonality of functions and systems will allow homeland security system applications to benefit from DoD's investment in MEMS technology for military systems.

Events that have occurred during the past 3 years have spurred the need to develop systems for homeland security applications. Because of the similarities that exist between DoD and DHS objectives and missions, DHS could benefit from the investment that DoD has made—and continues to make—in MEMS technology. Many opportunities exist for MEMS-based technologies to fulfill homeland security needs. Successful technology transition from DoD to a manufacturer and ultimately to an end user is critical if these emerging technologies are to be available to meet future challenges of DoD and homeland security missions.

One of the major challenges in advancing new technologies along the development path from concept demonstration to production for a specific application is the expense of fabricating the prototypes and performing field and operational testing. Joint efforts between DoD and DHS could reduce these costs for both agencies.

MILITARY APPLICATIONS AND POTENTIAL HOMELAND SECURITY APPLICATIONS FOR MICROELECTROMECHANICAL SYSTEMS (MEMS)

A. INTRODUCTION

In 1995, the Department of Defense (DoD) identified potential applications of MEMS technology in 12 types of military systems or subsystems. These applications were based on three major areas: Inertial Measurement Systems (IMSs), distributed sensing and control, and information technology (IT) (Ref. 1). The Defense Advanced Research Projects Agency (DARPA) was supporting MEMS technology development in these areas as early as 1992.

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B. MEMS TECHNOLOGY OVERVIEW

A basic understanding of MEMS technology is necessary to identify the potential uses for MEMS in commercial and defense products. MEMS technology is a manufacturing approach that chiefly uses integrated circuit (IC) fabrication processes to produce miniaturized mechanical structures integrated with microelectronic components (Ref. 1). Similar to IC processes, MEMS processes typically consist of a series of material deposition, patterning, and removal steps to form the mechanical and electrical components. Unlike IC applications, at least part of the structure of the mechanical components is released from the substrate and is free to move (Ref. 1). Three common MEMS batch fabrication processes used are surface micromachining, bulk micromachining, and LIGA.[1]

Surface micromachining is used to create structures by patterning and etching thin films that are deposited onto a wafer's surface. Typically, components have at least one feature (e.g., support spring width) with micrometer-sized dimensions. Depending on the number of structural layers used, the complete mechanical structures produced can be as thick as 10 μm. Surface micromachining is used to create structures for a variety of commercially available MEMS products, including accelerometers, rate sensors, and pressure sensors (Ref. 2).

Bulk micromachining uses wet-chemical or reactive-ion etching to remove material selectively from bulk wafers, usually single-crystal silicon (SCS), to form the MEMS structures. Released structures are formed through etching underneath a masking material applied to the wafer. Similar to surface micromachining, the structures created have at least one feature with micrometer-sized dimensions. Released bulk micromachined structures can also be formed when a substrate that contains a sacrificial material sandwiched between two structural materials is used. Typically, this type of substrate is formed by bonding one silicon wafer to another silicon wafer in between which is deposited a silicon oxide layer to serve as the sacrificial material. The released structure is formed through etching the top wafer and then removing the sacrificial layer using a material-selective etching technique (Ref. 2). Typical bulk micromachined structures are between 10 and 200 μm thick.

The LIGA process consists of deposition and patterning of thick photoresist and plating metal into the patterned resist. The most commonly used resist is polymethyl methacrylate (PMMA), which is patterned using x-ray exposure. Metals such as copper, nickel, and nickel-iron alloys can be plated into the patterned resist. When the patterned resist is removed, the metal LIGA structures remain (Ref. 2). LIGA structures are generally between 50 and 500 μm thick. As originally developed, the metal structures are still attached to the substrate and can be used as the final device or as a master for an injection mold. A sacrificial LIGA process was developed where the plating base deposited on the substrate is selectively removed and portions of the metal structures are released, similar to surface micromachined structures.

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1 LIGA is from the German Lithographie, Galvanoformung, und Abformung, meaning lithography, electroplating, and molding.

Because of continued R&D support from DoD, other government agencies, and industry, further advancements in MEMS technologies are anticipated. Research is continuing in refining existing processing methods, developing new processing methods, and introducing new materials for MEMS processes. Sponsors and researchers are motivated by the challenges and limitations in current MEMS processes and products and by the possibility of introducing new products that will meet a perceived need in the commercial or military market.

C. MEMS IN MILITARY SYSTEMS

1. Service Applications for MEMS

A 1995 DoD report identified 12 military systems/subsystems where MEMS technology application would affect military systems (Ref. 1):

1. Competent munitions	7. Identification, friend or foe (IFF)
2. Personal/vehicle navigation	8. Miniature analytical instruments
3. Displays	9. Biomedical devices
4. Situational awareness	10. Condition-based maintenance
5. Weapon fuze/safing and arming (F/S&A)	11. Mass data storage
6. Platform stabilization	12. Active structures.

In addition to the 1995 DoD report, a 2002 National Research Council (NRC) report on emerging microtechnologies and nanotechnologies stated that the following United States Air Force (USAF) systems and vehicles would benefit from advancements in microsystems (Ref. 3):

- Space vehicles and systems
- Weapon systems
- Air vehicles and systems.

Examples of specific opportunities cited in the NRC report for further advancements in microsystems (or MEMS) technologies are (Ref. 3):

- The development of large, distributed arrays of multifunctional and multispectral sensors
- The development of systems for propulsion and aerodynamic control for air and space vehicles

- The continued advancements in miniaturization of systems because of advancements in the integration of microscale and nanoscale processes.

While these are specific opportunities for USAF systems and vehicles, they are consistent with the broad areas cited in the 1995 DoD report.

Currently, MEMS technology is used in products for the following military systems:

- Competent munitions
- Display systems
- Sensors that provide information for situational awareness.

MEMS inertial measurement units (IMUs) have been developed for use in guidance and control (G&C) systems for missile and munition programs. Uncooled thermal imaging cameras using silicon microbolometers have been developed for helmet-mounted cameras and are available for soldier systems. Digital display systems, using MEMS micromirrors, are used in monitors for large-area displays [e.g., USAF Common Large-Area Display Set (CLADS)].

In addition to these systems, several components and systems have been demonstrated in relevant environments. Radio frequency (RF) MEMS switches, which survived harsh space launch and space exposure conditions, functioned as part of picosatellites that communicated with ground-based antennas (Ref. 4). Functional prototypes of a MEMS F/S&A device for a shipboard countermeasure, anti-torpedo weapon have been demonstrated in testing of experimental torpedoes (Ref. 4). Commercially available MEMS accelerometers have been demonstrated to survive and function after a high-g launch when incorporated into a gun round. The shock levels experienced were in excess of 30,000-g (Ref. 5). In the Reduced Ship's Crew by Virtual Presence Advanced Technology Demonstration (RSVP-ATD) program, several MEMS sensors were demonstrated in wireless sensor clusters for shipboard monitoring of environmental, structural, machinery, and personnel conditions. MEMS temperature, humidity, pressure, differential pressure, acceleration, and strain sensors were used. The functionality of the wireless sensor clusters was demonstrated under realistic conditions, including actual machinery and shipboard operating conditions, simulated failures, and damage-control conditions (Ref. 6).

2. DARPA MEMS Development Programs

MEMS technology development continues for many military systems and subsystems. DARPA is one of the leading agencies supporting MEMS technology development, mainly through programs in the Microsystems Technology Office (DARPA MTO).

DARPA has several programs for developing MEMS technology. These programs provide a clear indication that DARPA continues to support MEMS development for military systems consistent with the 1995 DoD report. **Note:** *Not all the MEMS-related programs at DARPA are presented.*

- **Chip Scale Atomic Clock (CSAC).** The CSAC program's goal is to create ultra-miniaturized, low-power, atomic time and frequency reference units that have the following characteristics compared with current reference units: at least a 200X reduction in size (from 230 cm^3 to less than 1 cm^3); at least a 300X reduction in power consumption (from 10 W to less than 30 mW); and matching performance (frequency stability) (i.e., Allen deviation of $\pm 1 \times 10^{-11}$ at 1-hr integration time). Potential military uses for the CSAC units include highly secure ultra-high frequency (UHF) communication and jam-resistant Global Positioning System (GPS) receivers (Ref. 7).
- **Micro Power Generation (MPG).** The MPG program's objective is to generate power at the microscale to replace bulky batteries in stand-alone microsystems (i.e., microsensor systems that have a wireless communication function). The goal is to produce power at a modest energy conversion efficiency of 10 percent from a higher energy-density fuel (e.g., a hydrocarbon fuel). A chemical-energy-to-electricity conversion efficiency such as this will allow the power generator to be 5 to 10 times smaller than conventional batteries (Ref. 8). Potential military uses are for unattended ground sensor (UGS) systems and for soldier system components where size and weight are critical factors.
- **Harsh Environment Robust Micromechanical Technology (HERMIT).** The HERMIT program was established to address the need for MEMS components and systems to be able to operate in extreme environments experienced by military systems. The HERMIT program's goal is to develop micromechanical devices that operate under harsh conditions, including high-g forces, long nonoperating storage times, high-power handling, exposure to corrosive substances, and large temperature differences. The devices developed under the HERMIT program should exhibit performance as good as or better than similar micromechanical devices that have been developed previously. For example, a MEMS rate sensor developed under the HERMIT program should have power consumption and stability performance as good as or better than currently available MEMS rate sensors (Ref. 9).

- **Micro Gas Analyzers (MGAs).** DoD interest in portable chemical warfare agent (CWA) detectors spurred DARPA to establish the MGA program, which has the ultimate objective of developing tiny separation-analyzer-based CWA sensors. When compared with equivalent bench top systems, these CWA sensors should be capable of orders-of-magnitude reductions in analysis time, detection limit, and power consumption while maintaining true and false alarm rates on par with bench top gas chromatograph/mass spectrometer (GC/MS) systems. Possible new applications for the CWA sensors developed under the MGA program include wearable sensors for dismounted warriors, projectile-delivered sensors for remote-detection applications, and UGSs for perimeter protection and advanced warning purposes. The Broad Agency Announcement (BAA) for the MGA program indicated the need for a combination of advancements in other areas of MEMS technologies (e.g., signal processing) to realize the portable CWAs. The BAA also identified possible civilian application of MGA sensors for environmental monitoring (Ref. 10).

As the previous discussion indicates, the development of MEMS technology for military systems is continuing in several of the 12 areas identified in the 1995 DoD report (Ref. 1). Because of events in the past 3 years, an urgent need exists to increase security at points of entry into and within the United States. The Department of Homeland Security (DHS) was established to unify efforts for protecting the United States from terrorist attacks. One might expect that many of the technologies and systems developed by DoD for military systems would be useful in systems developed for providing homeland security. To explore the possible common areas, the next section presents information on DHS and current areas of interest within DHS.

D. DHS MISSION AND INTERESTS

1. DHS Overview

The DHS was established in March 2003. It is the unifying core for the national network of organizations and institutions involved in efforts to secure the United States from terrorist attacks. Figure 1 provides an overview of DHS' objectives and mission areas (Ref. 11). The strategic objectives for DHS are to prevent terrorist attacks within the United States, reduce the nation's vulnerability to terrorism, and minimize the damage and assist in the recovery from such attacks (see Figure 1).

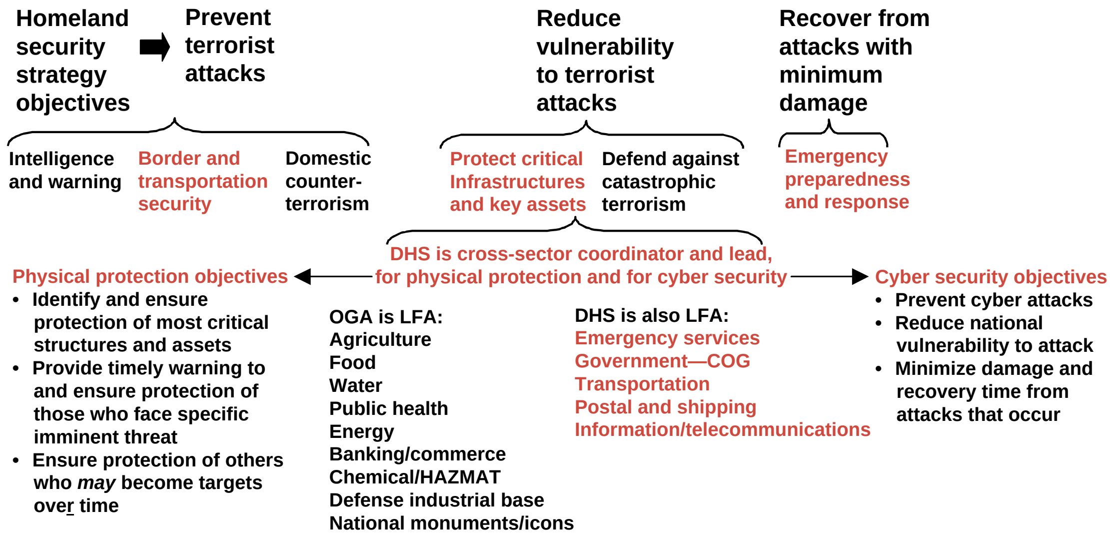

Figure 1. Homeland Security Objectives and Mission Areas

Note 1 for Figure 1: *The red text indicates primary DHS areas. However, DHS' role is significant in all mission areas, including those in which Other Government Agencies (OGAs) are the Lead Federal Agency (LFA).*

Note 2 for Figure 1: *COG is an acronym for Continuity of Government.*

DHS has five major divisions, or directorates, as follows (see Figure 2):

1. **Management Directorate.** This directorate provides administrative support to the other directorates.

2. **Border Transportation and Security (BTS) Directorate.** This directorate is responsible for maintaining the security of the country's borders and transportation systems. Included within the BTS are the Transportation Security Administration (TSA), the former U.S. Customs Service, the border security functions of the former Immigration and Naturalization Service (INS), and the Animal and Plant Health Inspection Service.

3. **Emergency Preparedness and Response (EPR) Directorate.** This directorate ensures that the Untied States is prepared for and able to recover from terrorist attacks and natural disasters.

4. **Information Analysis and Infrastructure Protection (IAIP) Directorate.** This directorate is charged with identifying and assessing a broad range of intelligence information concerning threats to the homeland, issuing timely warnings, and taking appropriate preventive action.

5. **Science and Technology (S&T) Directorate.** This directorate coordinates the DHS's efforts in R&D, including preparing for and responding to the full range of terrorist threats involving weapons of mass destruction (WMD).

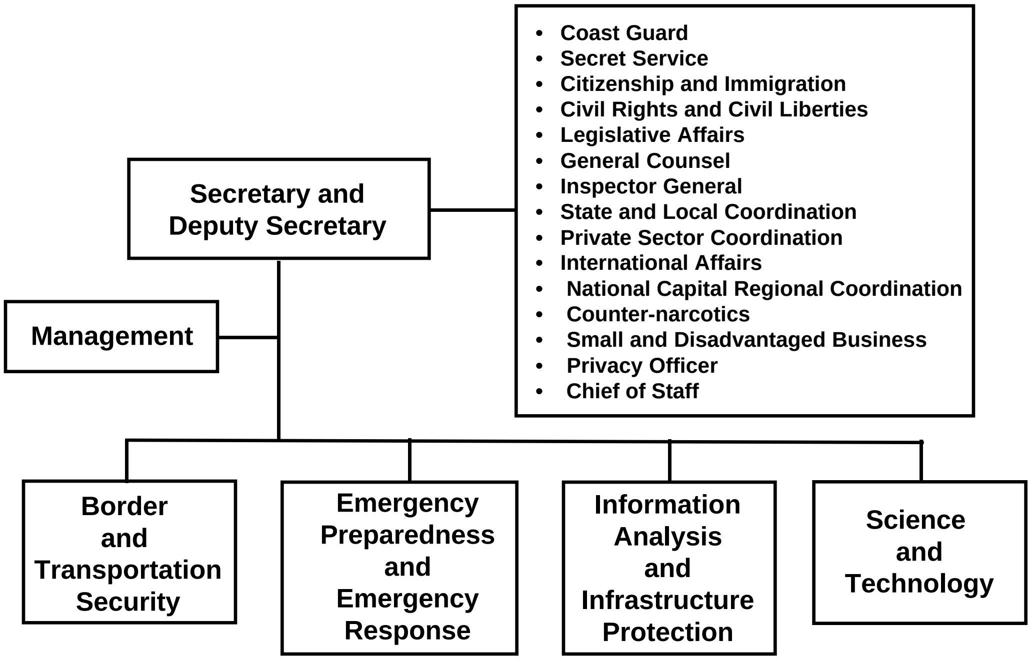

Figure 2. DHS Organization

Besides the five DHS Directorates, several other critical agencies have been incorporated into the new department (e.g., the Coast Guard and the Secret Service) or were newly created [e.g., the Bureau of Citizenship and Immigration Services (BCIS)].

2. DHS S&T Directorate Overview

The mission of DHS's S&T Directorate (see Figure 3) is to promote research, development, test, evaluation, and transition of homeland security capabilities to federal, state, and local operational end users. The role of the Office of Plans, Programs, and Budgets (PPB) is to define needs, identify gaps, and set priorities for programs. The roles of portfolio director are assigned to top staff within this office to ensure coordination of research among the DHS components. The numerous portfolio areas include crosscutting areas such as biological, chemical, radiological, nuclear, and explosive countermeasures; standards; safe communications; critical infrastructure protection; and cybersecurity. Also included are areas specifically tailored to the unique needs of a particular focus within DHS (e.g., the Secret Service). The Office of Research and Development (ORD) works with universities and government agencies on a noncompetitive basis on long-term research projects to provide the nation with an enduring research, development, test, and evaluation (RDT&E) base oriented toward homeland defense applications.

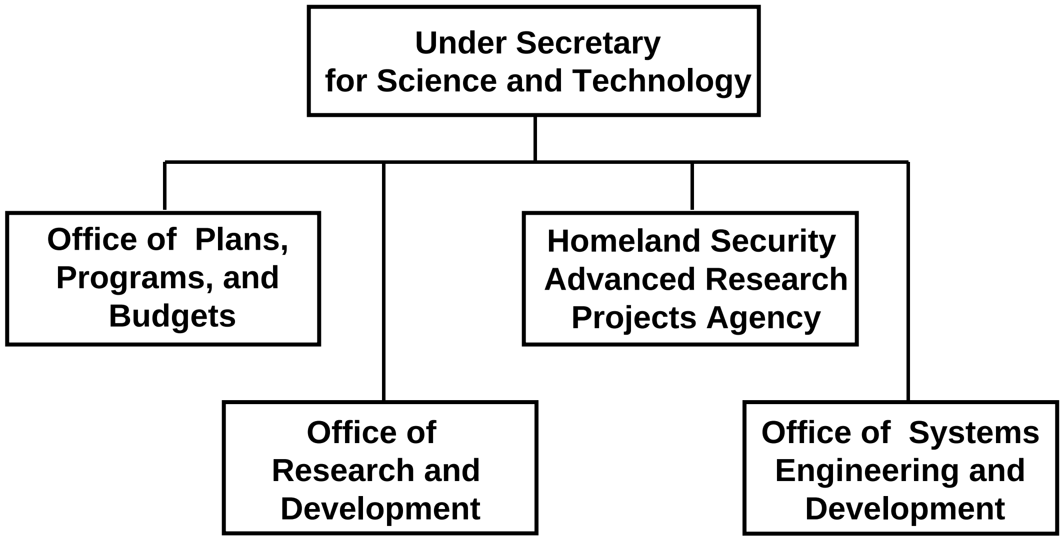

Figure 3. DHS S&T Directorate Organization

The Homeland Security Advanced Research Projects Agency (HSARPA) is the external funding arm for the DHS S&T division. HSARPA, like DARPA on which it was modeled, is intended to function as an independent entity that has the authority to make autonomous funding decisions. It awards R&D grants on a competitive basis to private, public, and academic sector entities to identify and develop new technologies, demonstrate rapid prototyping, and promote technology transfer and rapid technology deployment. About 90 to 95 percent of HSARPA's funds are earmarked for identified DHS requirements and target programs whose technologies will be ready for field deployment within 2 years. The remaining 5 to 10 percent of funds are intended for revolutionary research that will result in breakthroughs and new technologies and systems. In addition to developing systems to be used in addressing missions, HSARPA has a responsibility to establish standards for the systems developed in conjunction with the PPB.

HSARPA Budget: A 56-percent increase in Fiscal Year (FY) 2004 R&D funds over FY 2003 levels and the proposed 13 percent R&D budget increase for FY 2005 make the DHS S&T Directorate one of the fastest growing federal R&D budgets. The American Association for the Advancement of Science (AAAS) analysis of R&D in the FY2005 Federal Budget at http://www.aaas.org/spp/rd/prel05p.htm provides information on federal R&D funding.

HSARPA Current Programs: HSARPA issued its first research announcement solicitation for the Detection Systems for Biological and Chemical Countermeasures program on September 23, 2003, and has recently completed its first source selection (Ref. 12).

The goal of this program is to develop, field test, and transition to commercialization the next generation of biological and chemical detectors required to counter potential biological and chemical attacks within the United States.

The following projects are to be funded under the Detection Systems for Biological and Chemical Countermeasures program:

- **Bioagent Autonomous Networked Detectors (BAND).** BAND is intended to provide continuous distributed monitoring of outdoor urban areas. The BAND system will contain autonomous, networked biological sensors to sample the air for bacteria, viruses, and toxins.
- **Rapid Automated Biological Identification System (RABIS).** RABIS will develop systems for continuous monitoring of indoor environments plus selected outdoor locations. RABIS will contain fully autonomous sensors capable of identifying a variety of biological agents and will have a response time that provides sufficient warning to enable protection by limiting exposure.
- **Autonomous Rapid Facility Chemical Agent Monitor (ARFCAM).** ARFCAM will develop a system to monitor facilities continuously for CWAs and toxic industrial chemicals (TICs).
- **Lightweight Autonomous Chemical Identification System (LACIS).** LACIS will develop an autonomous, portable system for the detection of CWAs and TICs by first responders.
- **Portable High Throughput Integrated Laboratory Identification System (PHILIS).** PHILIS will be a rapidly deployable system capable of analyzing thousands of samples in the field per day to identify chemically contaminated areas.

Fieldable prototypes of these detection systems are to be developed, and a clear path to transition this technology to commercialization is to be established.

HSARPA Future Programs: New Research Areas New HSARPA research areas include detection systems for the Radiological and Nuclear Countermeasures program, which was announced in January 2004. This program's focus includes improved handheld identification systems, technology to identify and locate directly the nuclear and radiological threats on ships and in other locations, and area search devices that have enhanced resolution and penetration for cargo and parcels.

The research solicitation for the Bioinformatics and Assays Development (BIAD) program was released in April 2004. This program's goal is to extend the existing family of detection and forensics assays and to develop next-generation assays and new tools for assay development.

Other areas of interest identified by HSARPA include advanced container security devices and the detection of low-vapor-pressure chemicals. For specific information on any of the R&D areas of interest to DHS, the reader is encouraged to visit the HSARPA Web site (http://www.hsarpabaa.com/Solicitations/HSARPA_RA-03-01_Body.pdf).

When proof of concept is achieved on an HSARPA-funded project, the project is intended to transition to the Office of Systems and Engineering Development (SE&D). SE&D evaluates and develops the systems context for solutions, conducts rapid full-scale deployment and acceptance testing, and transitions to production and deployment. SE&D is to perform evaluations of risk, affordability, performance, and supportability for candidate systems. The project then transitions from SE&D to other parts of DHS. SE&D is intended to operate similarly to the DoD's 6.3 to 6.5 programs.

E. POTENTIAL HOMELAND SECURITY APPLICATIONS FOR MEMS TECHNOLOGY

DHS recognizes the need to develop and apply new technologies to meet DHS objectives. MEMS technology, along with many other technologies, is a candidate for use in future DHS systems. Based on the strategic objectives and related missions presented in Figure 1 and on the stated DHS S&T portfolio areas of interest (Ref. 13) in the PPB, DHS missions and systems appear to be similar to several DoD objectives and missions. For example, the DHS mission to protect critical infrastructure and assets might be considered similar to the DoD mission to protect military bases and installations.

In a broad sense, many DHS missions and systems fall into the category of situational awareness. A simple definition of situational awareness is the degree to which one's perception of the current environment mirrors reality. Based on this definition, MEMS devices and systems could be used in the following specific military applications that fall under the situational awareness category: perimeter security, shipboard automation, and area surveillance (Ref. 1). These specific applications are similar to the broad DHS objective and mission areas of border and transportation security, protection of critical infrastructures and key assets, and emergency preparedness response indicated in Figure 1.

Other military applications for situational awareness include displays, IFF, miniature analytical instruments, biomedical devices, mass data storage and condition-based maintenance. In a similar manner, the following paragraphs present some examples of potential

MEMS applications for DHS systems that fall in the application area of situational awareness.

Integrated networked sensors for chemical, biological, radiological, nuclear, explosive (CBRNE) detection are expected to have multiple uses in homeland security applications. MEMS technology can provide a generic sensor platform that can be customized to detect a range of chemical and biological targets. Small sensor elements can be placed on a single chip—each one customized to sense a particular physical property. This would enable selective, accurate, cost-effective sensors for detection, classification, and identification.

For continuous surveillance of border areas or urban terrain, unmanned aerial vehicles (UAVs) with on-board sensors could be used to provide wide area aerial reconnaissance for chemical and biological (CB) agent detection. Unattended CB sensor systems that can be distributed along a border or within an urban environment could complement the airborne systems. Microcantilevers or MEMS and nanostructures that use chemiresistors as sensor elements to recognize specific molecules are two of the sensing mechanisms that could be applied. Chemical detection capabilities can also be based on infrared (IR) absorption principles using standoff MEMS-based instruments. Portable standoff container inspection for trace detection of explosives could be accomplished using low-vapor-pressure chemical detection techniques coupled with MEMS technology.

Integration of biomaterials into MEMS processes and devices could result in biomedical sensor implants or wearable sensors for detecting biological warfare (BW) agents and other toxic substances and microchips for handling and analyzing biological samples. Biological detection through the examination of fluorescence or absorption of bioparticles in aerosols using spectrally tunable MEMS devices could be used for field screening and assessment tests for plant and animal threat mitigation. Handheld sensors and field analysis labs for emergency responders are highly desired as are tags for use in conjunction with information systems for trace-back capabilities for animals and inanimate resources.

MEMS-based imaging systems using microcantilever- or microbolometer-based pixels may be advantageous for nighttime surveillance activities. Tunable IR imaging systems in which spectral tuning is provided by MEMS elements would enable the location and identification of highly camouflaged targets through the detection of their unique spectral signatures.

In addition to situational awareness applications, MEMS-based technology is also expected to have utility in personnel and facilities protection and decontamination. Applications include air purification and body protection from all hazards. Nanotechnologies could be incorporated into microsystems to develop packaging material, gas masks, and protective clothing to mitigate the effects of chemical agents and biological pathogens. Protective gear may eventually contain wearable sensors and possess built-in decontamination capabilities. Wearable sensors that provide physiological information could be useful for monitoring the health of first responders (e.g., firefighters who work in physically taxing situations or are exposed to environments that have potentially toxic but unknown materials).

The *National Technology Plan for Emergency Response to Catastrophic Terrorism* report (Ref. 14) prepared by Hicks and Associates, Inc., delineates 12 response technology objectives (RTOs). These RTOs recommend R&D programs that the federal government can adopt to improve emergency response capabilities. This report also identifies five strategic research areas that offer the potential to provide the understanding and techniques that may permit breakthroughs in the following capabilities: nanotechnology; surface science; sensing for stand-off inspection of containers suspected of containing chemical or biological agents; ultra-wideband (UWB) communications; and biomarkers of agent-induced disease and injury in humans, animals, and plants. MEMS-based technology could be directly applicable in most or all these areas.

Table 1 summarizes areas in which homeland security applications might benefit from DoD's investment in MEMS technology. The use of MEMS technology is feasible in all the military systems shown in the leftmost column. In the **Homeland Security Applications** column, the systems for which commonality has been discussed are indicated by a check mark (√), other possible opportunities not discussed in this document are indicated by an asterisk (*), and systems that are not applicable to homeland security are indicated by N/A.

F. LEVERAGING MILITARY TECHNOLOGY AND DEVICES FOR HOMELAND SECURITY APPLICATIONS

Many similarities exist between military and homeland security missions. For example, DoD owns and operates an extensive infrastructure of installations, some of which resemble self-sufficient municipalities. DoD installations are responsible for providing their own fire service, law enforcement, security, operations, and maintenance. DoD also employs

Table 1. Potential Applications of MEMS in Military Systems and Homeland Security Applications

Potential Military System	Homeland Security Applications
Competent munitions	N/A
Personnel/vehicle navigation	*
Display systems	√
Situational awareness	√
Weapon F/S&A	N/A
Platform stabilization	*
IFF	*
Miniature analytical instruments	√
Biomedical devices	√
Condition-based maintenance	*
Mass data storage	*
Active substructures	*

civilian police officers, security guards, and numerous other personnel involved in operating and maintaining the bases. The needs of DoD's personnel are likely to be the same as or similar to the needs of employees working for cities, counties, states, and other federal departments and agencies. Therefore, technology and devices developed for military users may also find applications in homeland security areas.

Finding a way to share with the civilian community some of the technologies that DoD has developed for its own purposes is a desirable goal. However, while the military and homeland security missions may be similar, the specific device and system requirements may differ. Consequently, technology and devices developed for military uses may need to be adapted to address homeland security mission needs successfully.

One of the major challenges in advancing new technologies along the development path from concept demonstration to production for a specific application is the expense of fabricating the prototypes and performing field and operational testing. DoD funds this part of the development path for devices that have military applications. At this time, however, it does not do the same for devices that can also be used for homeland security applications. If similar needs between DoD and DHS are identified early in the development cycle, development and, ultimately, production costs might be reduced if DoD and DHS work together to commercialize attractive technologies (e.g., MEMS).

Both DHS and DoD have Congressional mandates to facilitate technology transfer to civilian emergency responders. At the federal level, DHS has the primary responsibility and is the lead for standards development. DoD plays a supporting role. Joint programs between DoD and DHS could facilitate the development of homeland security applications that use technology or devices originally developed by DoD for military applications. If civilian applications could be considered during the initial stage of technology development for military applications, required modifications could be identified early, and optimum solutions could be achieved for both military and homeland security applications. DHS could provide supplemental funding from the point at which the technology is considered for a civilian application.

Some other factors that must be considered when sharing technology between DoD and civilian applications include interoperability, standards, affordability, and compatibility with existing equipment. To be able to mount an effective response to a catastrophic terrorist act, any useful systems must be interoperable across federal, state, and local emergency response organizations and agencies. Current gaps in interoperability among the various systems have sometimes prevented a concerted teaming effort. Developing standards and then testing to those standards will be an important enabler of interoperability. Setting standards is not straightforward since different civilian groups often use incompatible equipment and procedures. Laws also vary from state to state and between different localities, which further complicates the issue. Since state and local governments that employ most front-line civilian personnel traditionally have limited funding resources, the products must be affordable to be of practical benefit. Systems must integrate well with current equipment and infrastructure. End users will not be able to afford systems that require the complete replacement of existing equipment and infrastructure.

G. SUMMARY

MEMS technology has been under development to address DoD mission and capability needs for over a decade. Events that have occurred during the past 3 years have spurred the need to develop systems for homeland security applications. Because of the similarities that exist between DoD and DHS objectives and missions, DHS could benefit from the investment that DoD has made—and continues to make—in MEMS technology. In addition to the opportunities cited in this document, many other opportunities exist for

MEMS-based technologies to fulfill homeland security needs. Successful technology transition from DoD to a manufacturer and ultimately to an end user is critical if these emerging technologies are to be available to meet future challenges of DoD and homeland security missions. Coordination between DoD and DHS could facilitate this effort.

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GLOSSARY

AAAS	American Association for the Advancement of Science
ARFCAM	Autonomous Rapid Facility Chemical Agent Monitor
ARL	Army Research Laboratory
BAA	Broad Agency Announcement
BAND	Bioagent Autonomous Networked Detectors
BCIS	Bureau of Citizenship and Immigration Services
BIAD	Bioinformatics and Assays Development
BTS	Border Transportation and Security
BW	biological warfare
CB	chemical and biological
CBRNE	chemical, biological, radiological, nuclear, explosive
CLADS	Common Large-Area Display Set
COG	Continuity of Government
CRP	Central Research Program
CSAC	Chip Scale Atomic Clock
CWA	chemical warfare agent
DARPA	Defense Advanced Research Projects Agency
DHS	Department of Homeland Security
DoD	Department of Defense
DSN	Dependable Systems and Networks
EPR	Emergency Preparedness and Response
F/S&A	fuze/safing and arming
FY	Fiscal Year
G&C	guidance and control
GC/MS	gas chromatograph/mass spectrometer
GPS	Global Positioning System
HAZMAT	hazardous material
HERMIT	Harsh Environment Robust Micromechanical Technology
HSARPA	Homeland Security Advanced Research Projects Agency
IAIP	Information Analysis and Infrastructure Protection

IC	integrated circuit
IDA	Institute for Defense Analyses
IEEE	Institute of Electrical and Electronics Engineers
IFF	identification, friend or foe
IMS	Inertial Measurement System
IMU	inertial measurement unit
INS	Immigration and Naturalization Service
IR	infrared
IT	information technology
LACIS	Lightweight Autonomous Chemical Identification System
LFA	Lead Federal Agency
LIGA	Lithographie, Galvanoformung, und Abformung (lithography, electroplating, and molding)
MEMS	Microelectromechanical Systems
MGA	Micro Gas Analyzers
MPG	Micro Power Generation
MTO	Microsystems Technology Office (DARPA)
NRC	National Research Council
OGA	Other Government Agency (Federal)
ORD	Office of Research and Development
PHILIS	Portable High Throughput Integrated Laboratory Identification System
PMMA	polymethyl methacrylate
PPB	(Office of) Plans, Programs, and Budgets
PPE	personal protective equipment
R&D	research and development
RABIS	Rapid Automated Biological Identification System
RDT&E	research, development, test, and evaluation
RF	radio frequency
RSVP-ATD	Reduced Ship's Crew by Virtual Presence-Advanced Technology Demonstration
RTO	response technology objective
S&T	Science and Technology
SCS	single-crystal silicon
SE&D	(Office of) Systems and Engineering Development
TIC	toxic industrial chemical

TSA	Transportation Security Administration
UAV	unmanned aerial vehicle
UGS	unattended ground sensor
UHF	ultra-high frequency
USAF	United States Air Force
UWB	ultra-wideband
WMD	weapons of mass destruction

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14. ABSTRACT

The Department of Defense (DoD) continues its strong support of research and development (R&D) in Microelectromechanical Systems (MEMS) technology for military system applications. Systems useful for homeland security applications could benefit from the MEMS investment for military systems. This document reviews past and current DoD MEMS developments for military systems and identifies potential applications of MEMS technology to homeland security devices and systems. For the areas cited where MEMS has potential application in military systems and homeland security systems, coordination between DoD and DHS throughout the development cycle is recommended.

15. SUBJECT TERMS

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